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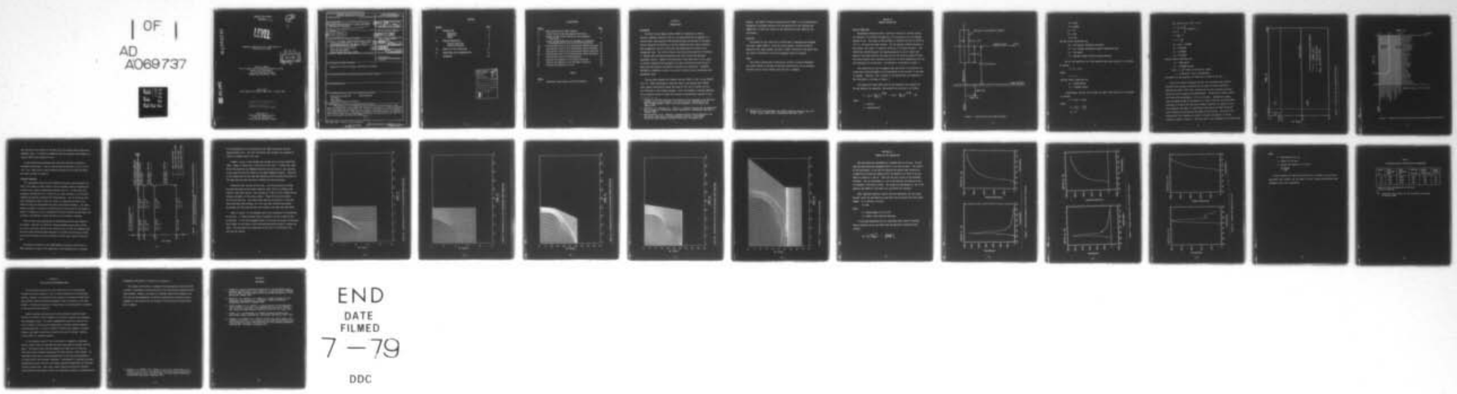

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Lagrangian Calculation of a High Explosive Detonation Over Water

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Calculations of a propagating water shock wave resulting from a high explosive detonation in air, above the surface of the water is a difficult problem for a Lagrangian wave propogation code to handle accurately due to the resulting severe mesh distortions. This report documents a successful attempt at calculating this problem using the two-dimensional Lagrangian wave propogation code TOODY II and its associated rezoning code TOOREZ.

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ILLUSTRATIONS

TABLES

SECTION I

INTRODUCTION

BACKGROUND

The Naval Surface Weapons Center (NSWC) is attempting to obtain a practical computer solution to the air and water shock wave propagation resulting from a high explosive (HE) detonation above the surface of the water. Earlier hydrocode calculations of the HE problem were done using an Eulerian wave propagation code and an Eulerian code coupled with an acoustic wave propagation code. The results from one such calculation reported in reference 1, indicate that the Eulerian/acoustic shock wave calculation generated reasonable results. However, the resolution of the shock wave is not as good as could be expected from Lagrangian shock wave calculations where the grid moves with the material and material interfaces are maintained. Therefore, the NSWC is attempting to obtain a practical solution using a Langrangian wave propagation code.

The two codes proposed for feasible use were TOODY II (ref. 2) and STEALTH (ref. 3). After investigation into both codes it was decided that STEALTH would require modification beyond the scope of this task to handle the size and difficulty of the problem proposed. Also, the automatic rezoning capability was not general enough to handle the severity of deformations expected in this

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1. Lutsky, M., *Eulerian Hydrocode Calculations of the Detonation of an Explosive Cylinder Above a Water Surface: an Interim Report*, NSWC/WOL/TR-77-34, Naval Surface Weapons Center, White Oak Laboratory, Silver Spring, MD, January 1978.
2. Bertholf, L.D., Benzley, S.E., *TOODY II, A Computer Program for Two-Dimensional Wave Propagation*, SC-RR-68-41, Sandia Laboratories, Albuquerque, New Mexico, November 1968.
3. Ronald Hofmann, et al, *STEALTH, A Lagrange Explicit Finite-Difference Code for Solids, Structural, and Thermohydraulic Analysis*, EPRI-NP-160, Electrical Power Research Institute, Palo Alto, CA, August 1976.

problem. The author's extensive experience with TOODY II in calculating wave propagation in geologic materials and the generality of the rezoning code TOOREZ (ref. 4) were also factors in the selection of these codes for the calculation.

OBJECTIVE

The purpose of this effort was to verify that a Lagrangian wave propagation code, namely TOODY II, could be used to obtain a solution to the HE detonation over water problem, and that a higher resolution of the water shock wave would be obtained by using the Lagrangian frame of reference.

SCOPE

This effort concentrated on obtaining a solution to the HE detonation over water problem in the form of pressure time histories at the air/water interface and at various depths along the axis at symmetry.

---

4. Thorne, B.J., and Holdridge, *The TOOREZ Lagrangian Rezoning Code*, SLA-73-1057, Sandia Laboratories, Albuquerque, NM, April 1974.

SECTION II
PROBLEM DESCRIPTION

INITIAL CONDITIONS

The general problem for which a practical solution is desired consists of a 454 gm (1 lb) cylinder of pentolite, 17 cm long and 4.6 cm in diameter ignited in air. The center of the cylinder is located from 15.24 to 30.48 cm (.5 to 1. ft) above the water surface. For the specific problem discussed in this report, the center is located at 30.48 cm (1 ft) above the water. This problem was selected because the expected pressure in the air shock upon impact on the water would be less than that for the 15.24 cm height-of-burst. This would simplify the calculation during the air shock transmission into and the reflection off of the water. The problem is illustrated in figure 1.

The problem has an axis-of-symmetry down the center of the penolite cylinder and a plane-of-symmetry at the mid-height of the cylinder if the water is ignored. Therefore, only a quarter of the problem had to be modelled in the calculation, also shown in figure 1.

The equation-of-state (EOS) used for the detonation gas products was the JWL equation for pentolite. The equation for pressure is as follows:

$$P = A\left(1.0 - \frac{W\rho}{R_1\rho_0}\right)e^{-\frac{R_1\rho_0}{\rho}} + B\left(1.0 - \frac{W\rho}{R_2\rho_0}\right)e^{-\frac{R_2\rho_0}{\rho}} + W\rho\varepsilon$$

where,

ρ = density

ε = energy density

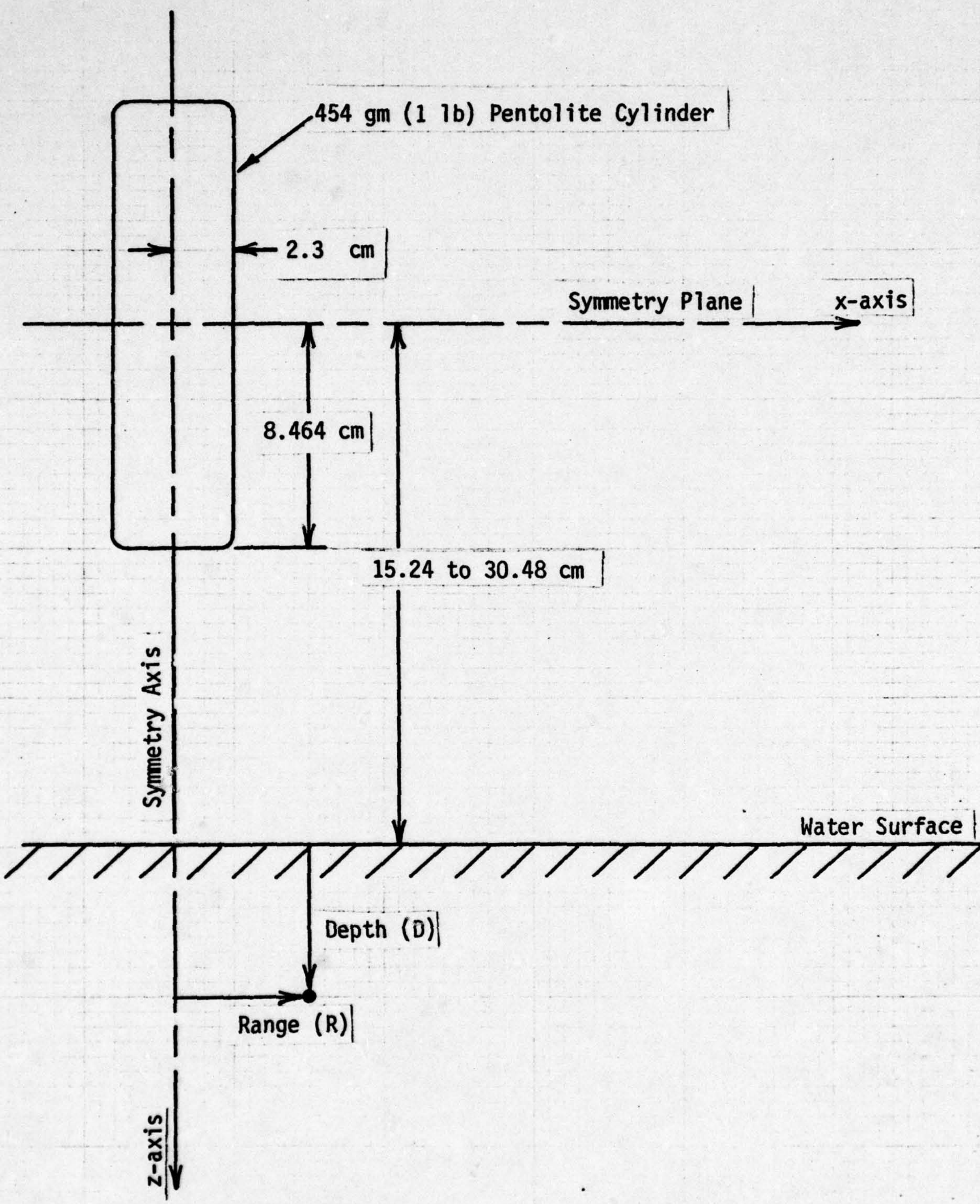

Figure 1. High Explosive Over Water Problem

$$A = 5.3177$$

$$B = 0.08933$$

$$R_1 = 4.6$$

$$R_2 = 1.05$$

$$W = 0.33$$

And the initial conditions are,

D_0 = .736 cm/μsec (detonation velocity)

b_5 = 2.5, constant determining width of detonation wave

ρ_0 = 1.65 gm/cm^3

ε_0 = .080 Mbar-cm/gm (reference energy density)

The air was modelled as an ideal gamma-law gas where pressure is calculated as follows:

$$P = (\Gamma - 1)\,\rho\varepsilon$$

where,

$$\Gamma = 1.4$$

and the initial conditions are,

ρ_0 = .001225 gm/cm^3

C_0 = .0340294 cm/μsec

A hydrodynamic EOS was used to model the water where pressure is calculated as follows:

$$P = f_1(\rho) + f_2(\rho)\varepsilon$$

where,

$$f_1 = P_H\left(1 - \frac{\Gamma\mu}{2}\right)$$

$$f_2 = \Gamma\rho$$

$$P_H = K_0 \eta (1 + K_1 \eta + K_2 \eta^2 + K_3 \eta^3)$$

$$\left.\begin{aligned} \Gamma &= \Gamma_0 (1-\eta) \\ B &= 1 \end{aligned}\right\} \text{Constant } \Gamma\rho$$

$$\mu = \frac{\rho}{\rho_0} - 1$$

$$\eta = 1 - \frac{\rho_0}{\rho}$$

$$K_0 = \rho_0 C_0^2 = .0219504$$

$$K_1 = 3.7815448$$

$$K_2 = 2.8199746$$

$$K_3 = 115.79338$$

and the initial conditions are,

$$\rho_0 = .9982 \text{ gm/cm}^3$$

$$C_0 = .14785468 \text{ cm}/\mu\text{sec}$$

$$P_{min} = -1.\text{x}10^{-6} \text{ Mbar (1 atm tension cutoff)}$$

$$\nu = .5 \text{ (Poisson's ratio, hydrodynamic)}$$

For details of the equations of state used in TOODY II see ref. 3.

The initial finite difference grid for the calculation was setup for efficient core storage utilization and for ease of future rezoning by defining the overall grid size, locating the air water interface and fine zoning the active region of the problem only. The HE and air region nearby were zoned with approximately .25 by .25 cm zones. Outside this region zones extended to edge of the problem at a range of 200 cm, to the air/water interface at 30.48 cm and from the air/water interface to a depth of 70 cm. This minimizes the number of calculations that have to be done during any given time/cycle by minimizing the number of grid points. The grid at the beginning of the calculation is shown in figure 2 and details of the HE zoning are shown in figure 3. The grid plots in the remainder of the report show

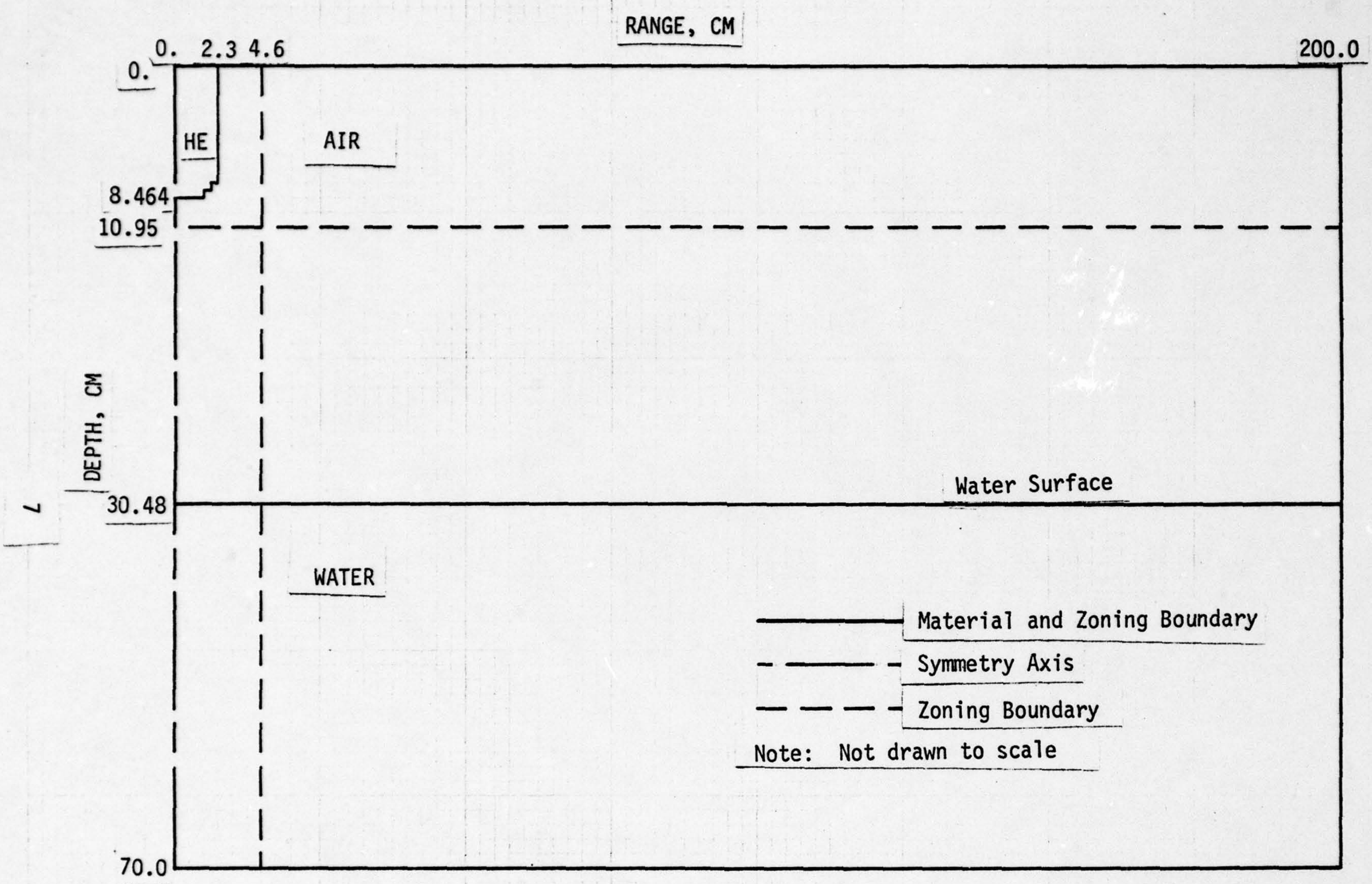

Figure 2. Initial Grid for the Lagrangian Calculation

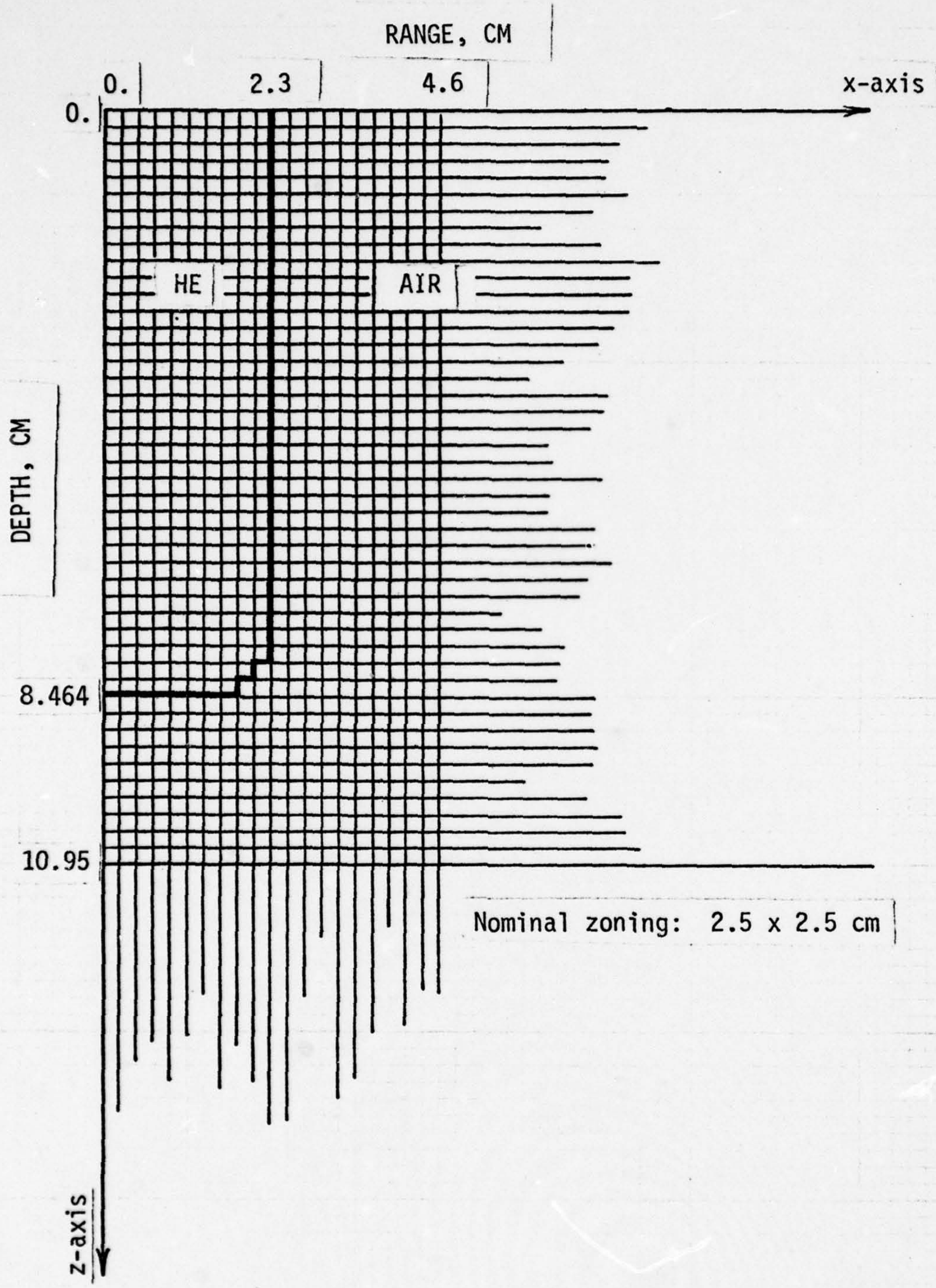

Figure 3. Details of the Initial Zoning for the Lagrangian Calculation

only the grid in the region of the shock wave (the region where pressure has exceeded 1 bar). It should be remembered that the complete grid extends to a range of 200 cm and a depth of 70 cm.

As the calculation progressed zone sizes were selected to maintain a reasonably uniform grid. The air and HE zones varied from 1.5 by 2.5 cm to 1. by .5 cm. When the air shock reached the surface of the water the water was zoned as shown in figure 4.

REZONING PROCEDURE

In a Lagrangian frame work the reference grid moves with the material so that in the region of shock fronts a grid can become severely distorted particularly for a highly compressible material like air. As the shock wave propagates through the air it crushes up air zones resulting in a very small timestep and possibly unstable grid configurations. Also as the HE gas products approach the water surface air zones are compressed and the air is forced to flow out from between the water and explosive products. For these reasons rezoning is required to redistribute the grid points in the region of shocks, to remove air cells from between the HE gas products and the water and to place a frictionless sliding interface at the air/water interface.

Three criteria were established for determining when the grid needed to be rezoned. They were (1) when the timestep dropped by more than a factor of 2 in any one cycle indicating an unstable zone, (2) when the timestep dropped below some selected minimum timestep or (3) when the activity was within one zone of the edge of the well defined or finely zoned region of the problem.

The general procedure for the TOODY/TORREZ calculations consisted of a TOODY execution, a restart file generation of the deformed grid, a rezoning

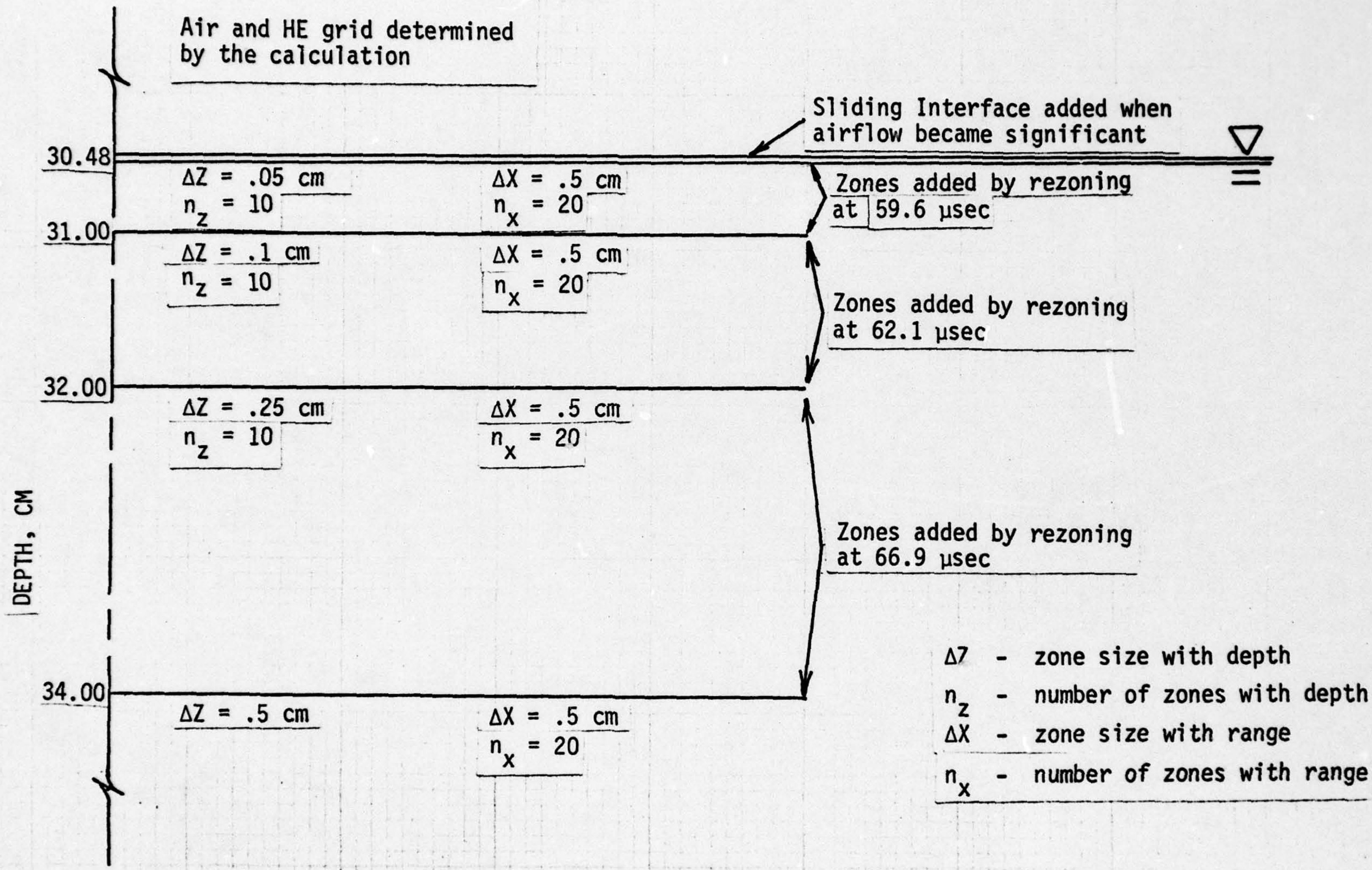

Figure 4. Initial Zoning Definition for the Water as Generated by Rezoning at 59.6, 62.1 and 66.9 Microseconds

of the deformed grid, and restarting of the TOODY calculation from the rezoned restart file. For this calculation this procedure was repeated 23 times to a problem time of 113 μsec.

Figures 5, 6 and 7 show deformed and rezoned grids at three significant times. Shown in figure 5A is a grid plot at 10.7 μsec. It shows that about 75% of the pentolite has detonated and that the shock wave is just starting to pull away from the HE products at the upper symmetry boundary. Figure 5B is the rezoned grid at the same time showing the redistributed grid points in the shock wave and that the HE/air interface has been maintained.

Figure 6A shows the grid at 59.6 μsec. The entire pentolite cylinder has been detonated and the almost spherical shock front is evident by the region of very dense zoning. The crushing up of the air cells between the HE products and water is also quite evident. Figure 6B shows the rezoned grid at the same time. The figure shows that the grid points in the shock front have been redistributed, air cells have been removed from between HE products and the water and very fine zoning of the water has been added.

Shown in figure 7 is the deformed grid at the termination of the problem at 113 μsec. It shows the shock wave to be about 5 cm out in front of the HE products. It has also propagated about 24 cm along the surface of the water. Also evident in the figure is the reflected shock wave located 5 cm above the water. The calculation was terminated at this point and therefore, this grid was not rezoned.

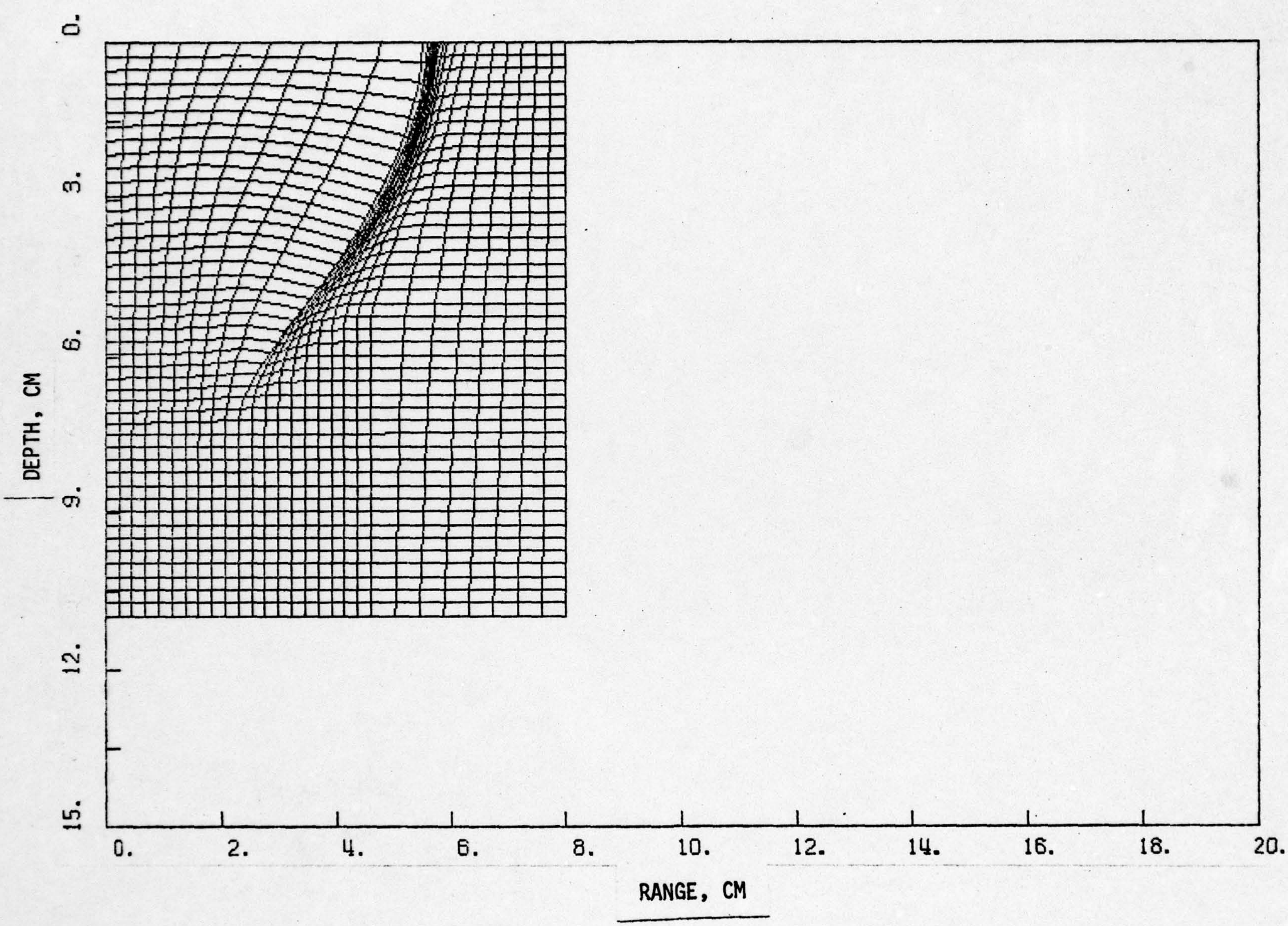

Figure 5A. Calculational Grid at 10.7 Microseconds (Before Rezoning)

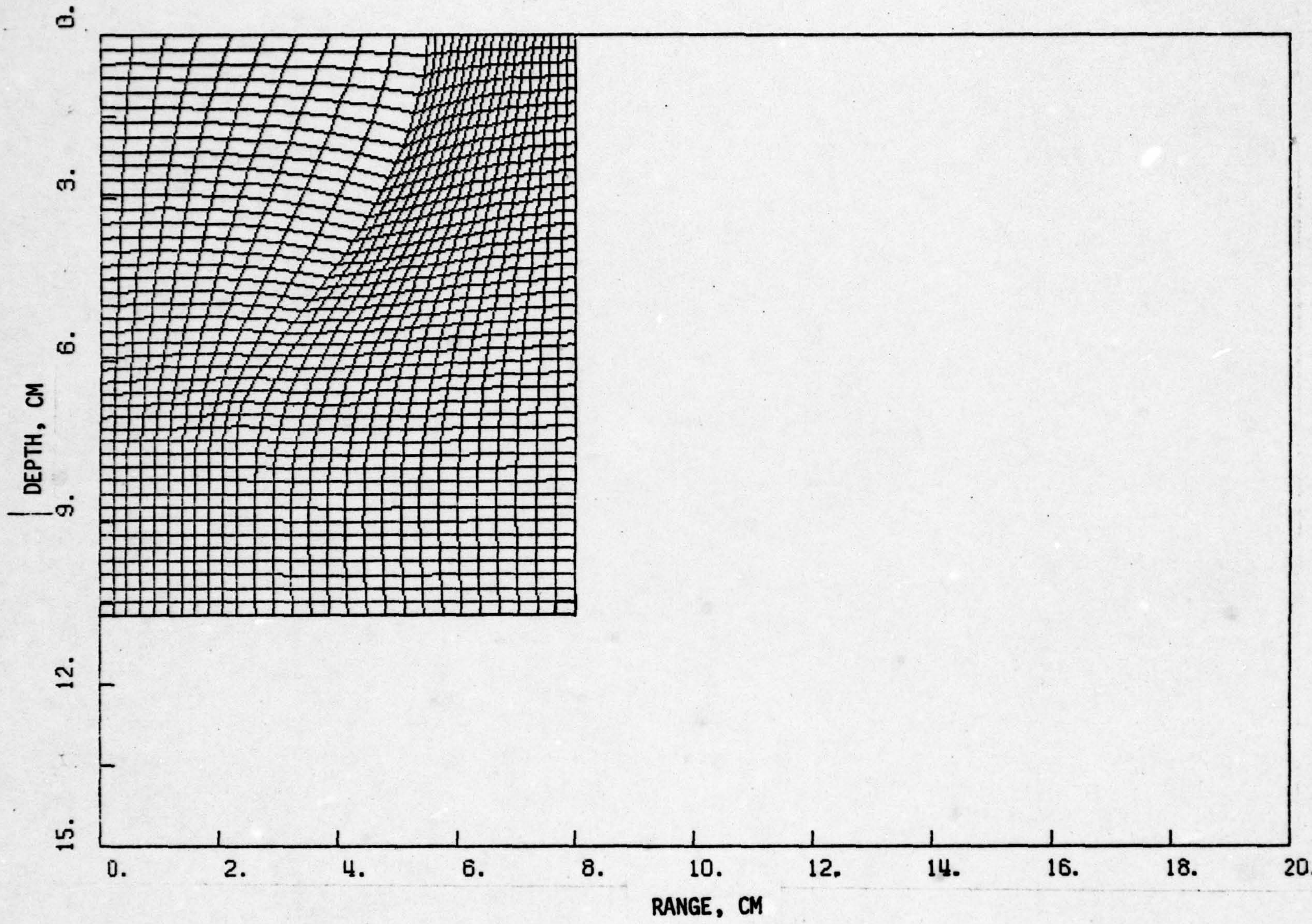

Figure 5B. Calculation Grid at 10.7 Microseconds (After Rēzoning)

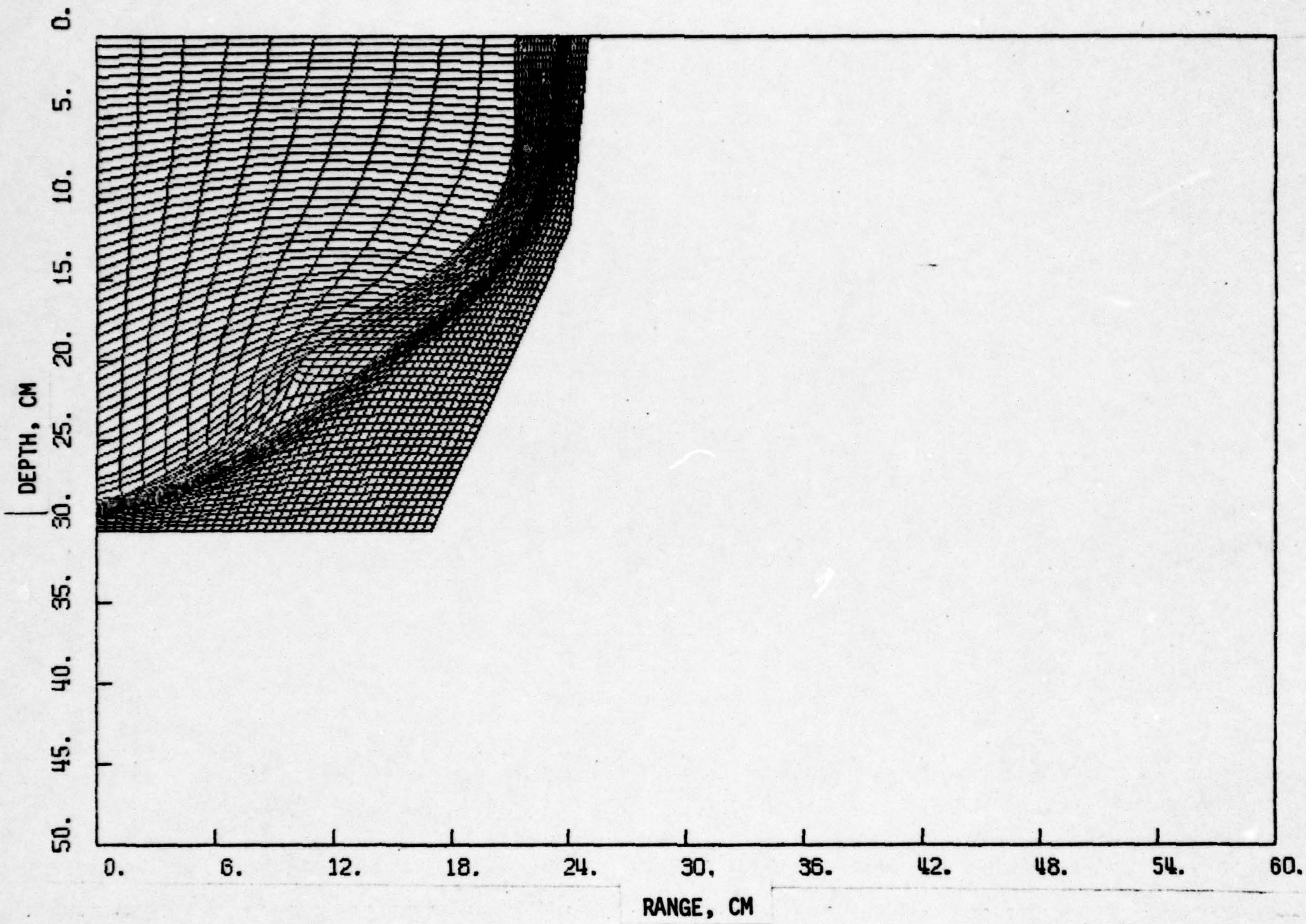

Figure 6A. Calculational Grid at 59.6 Microseconds (Before Rezoning)

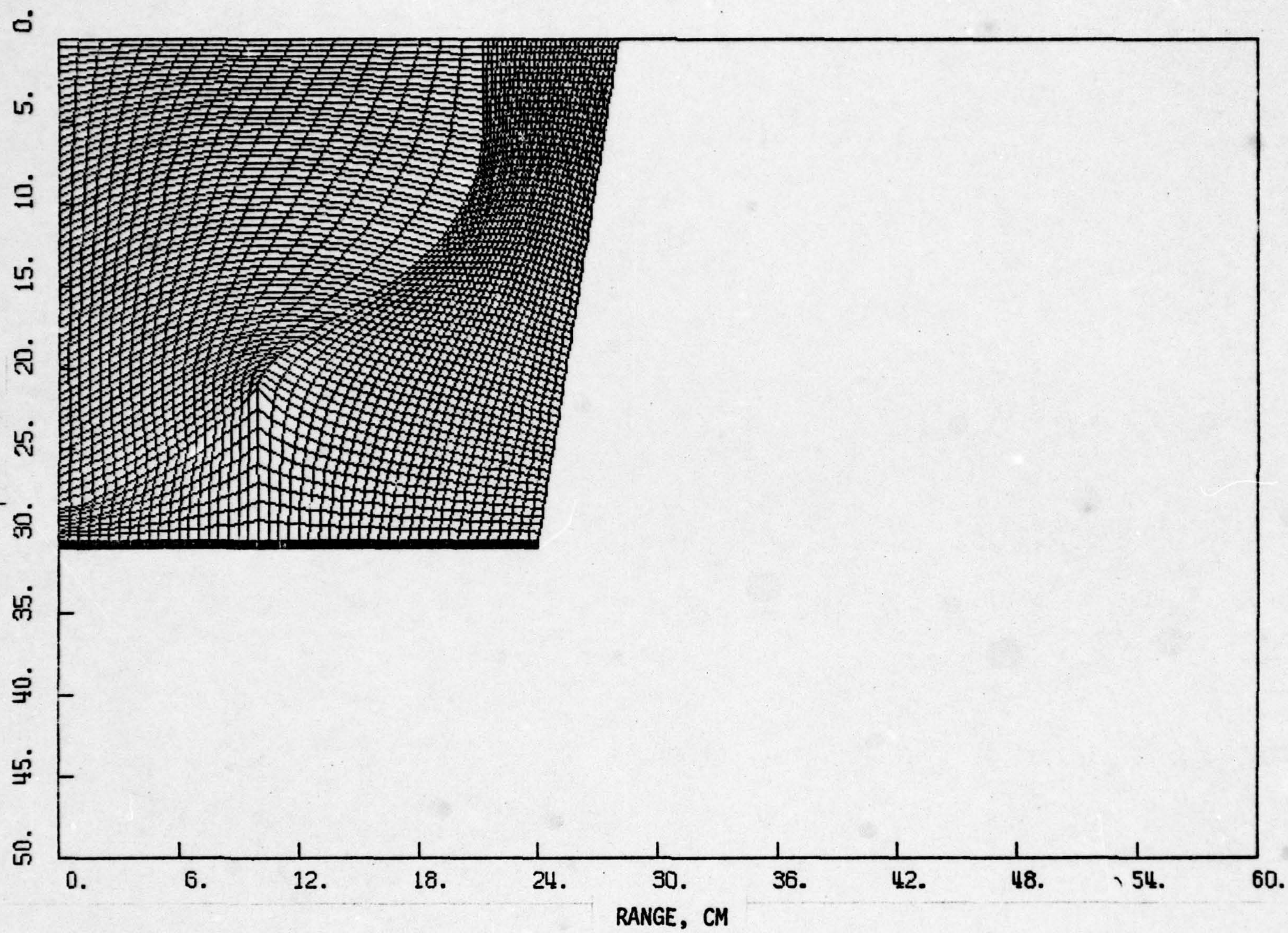

Figure 6B. Calculational Grid at 59.6 Microseconds (After Rezoning)

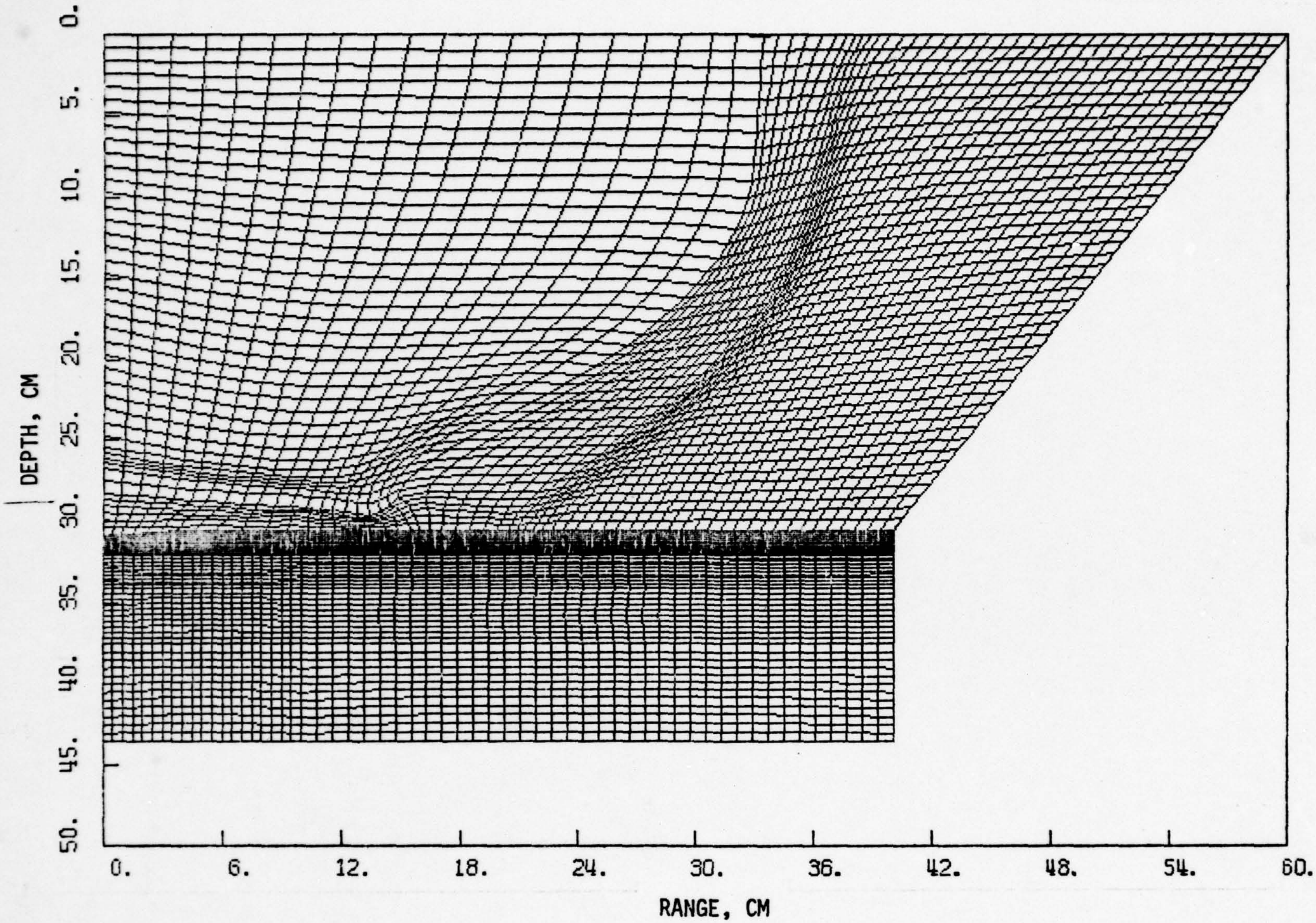

Figure 7. Calculational Grid at 113 Microseconds

SECTION III

RESULTS OF THE CALCULATION

The calculation was terminated at a problem time of 113 μsec. At this time the shock wave had propagated about 7.5 cm into the water. The results of the calculation, in the form of pressure and impulse time histories at a range 0.0 cm (along the symmetry axis) and depths of 0.0 and 4.2 cm, are shown in figures 8, 9 and 10. There are two sets of data at the air/water interface. One set (designated -0. cm) is the pressure and impulse in the air adjacent to the water surface. The second set (designated +0. cm) is the pressure and impulse in the water cell just below the interface.

Other important numerical results from the computation are the "shock factors" which are semi-empirical quantities that correlate well with target damage. It is defined as follows:

$$Q = W/R$$

where,

W = charge weight in lbs of TNT

R = range in feet from the explosive

It has been determined that an "equivalent shock factor" resulting from an airblast can be calculated from the analytical expression that follows:

$$Qe = \frac{1}{2}\left[\frac{\sqrt{I}\,P^{.491}}{5133} + \frac{.02416\sqrt{E}}{P^{.0177}}\right]$$

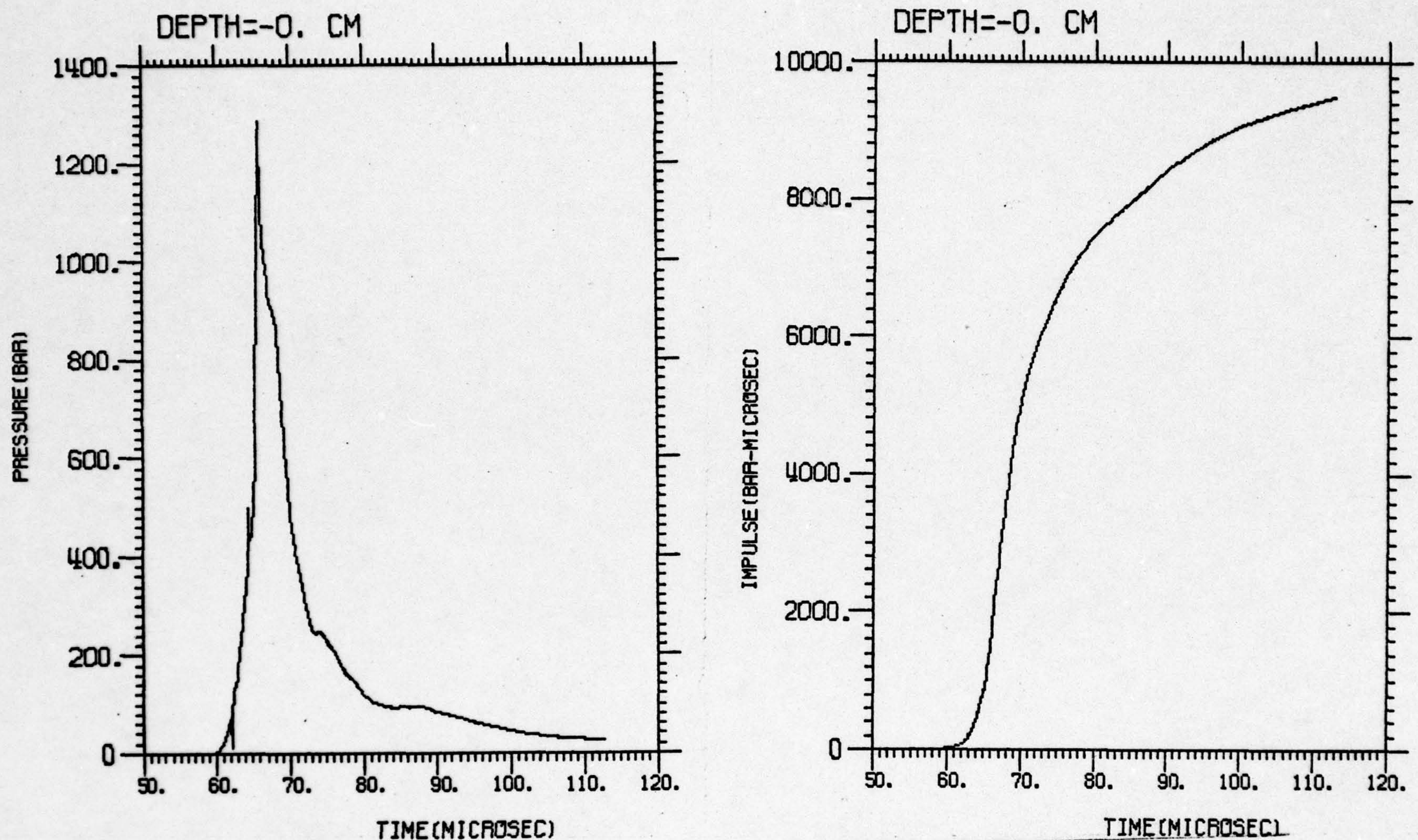

Figure 8. Pressure and Impulse at -0.0 CM (Air Pressure)

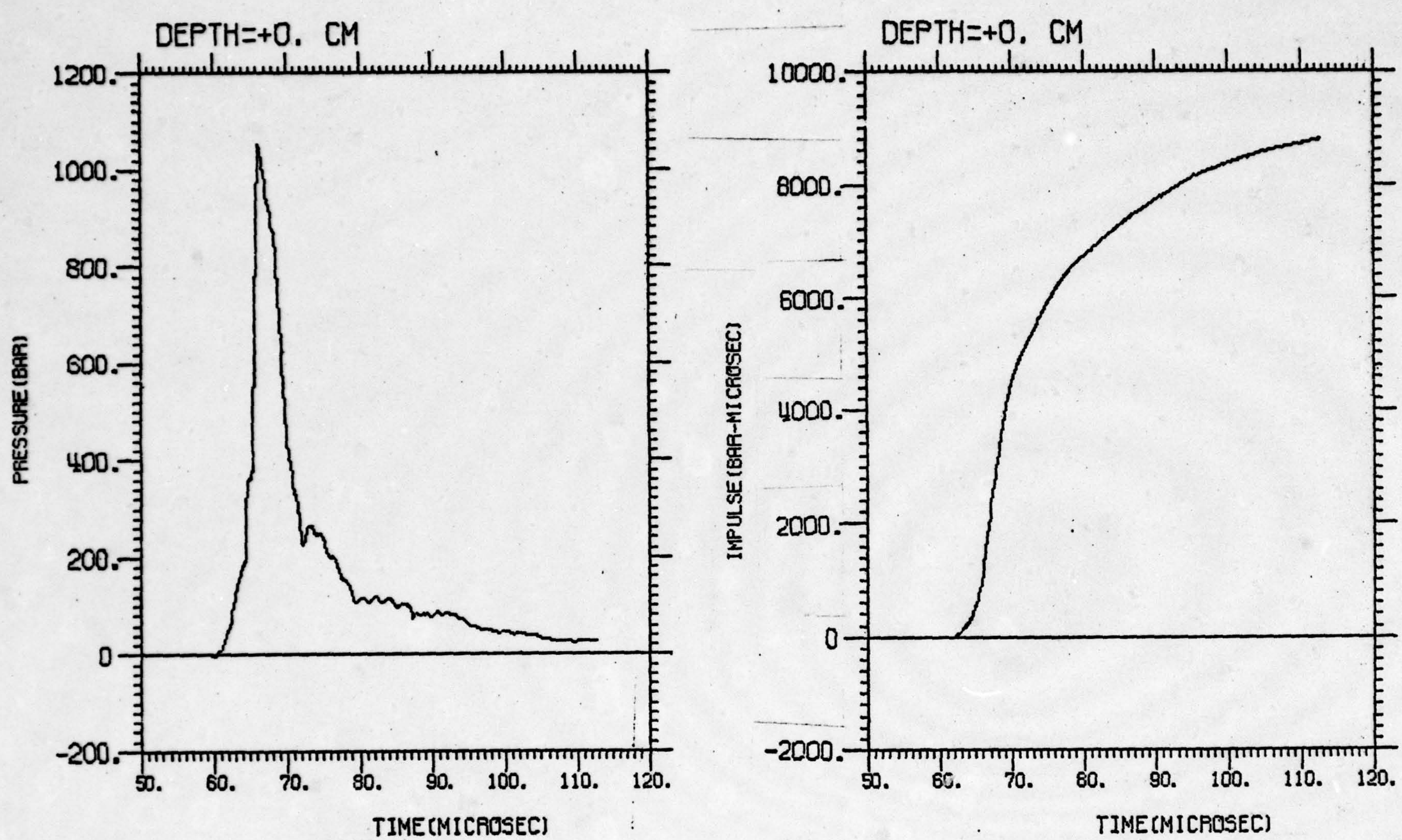

Figure 9. Pressure and Impulse at +0.0 CM (Water Pressure)

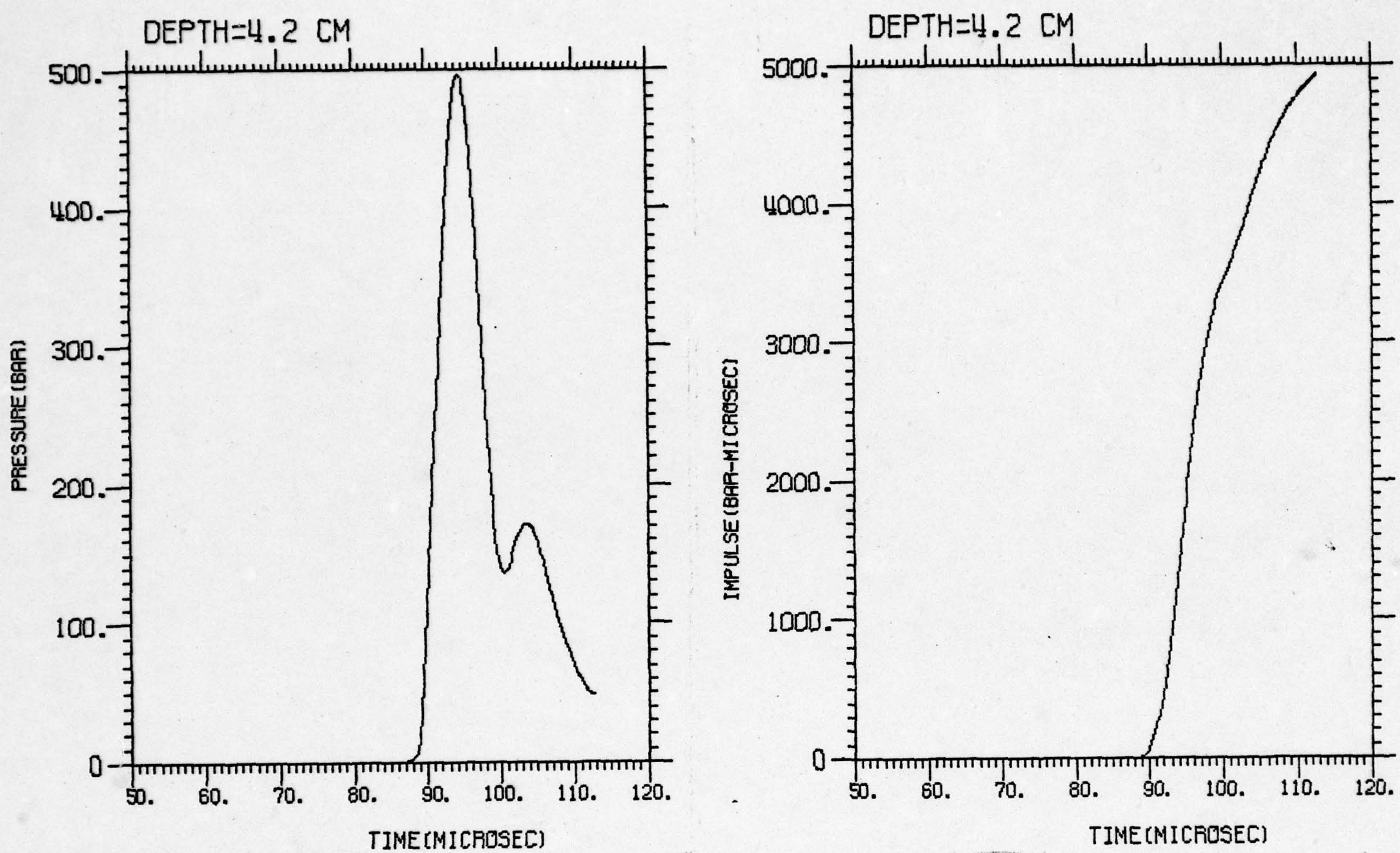

Figure 10. Pressure and Impulse at 4.2 CM

where,

P = peak pressure in, psi

I = impulse in psi-msec

E = energy flux density in in-lbs/in^2

$$= \frac{\int P(t)^2 dt}{\rho_0 C_0}$$

For the pressure and impulse time histories in figures 8, 9 and 10 the equivalent shock factors, Qe, are shown in Table 1 along with pertinent peak parameters used in Qe calculations.

TABLE 1

EQUIVALENT SHOCK FACTORS AND PEAK PARAMETERS

DEPTH, CM	PEAK PRESSURE, BARS	PEAK PRESSURE, PSI	IMPULSE, PSI-MSEC	ENERGY FLUX, IN-LBS/IN^2	SHOCK FACTOR Qe **
-0.	1285	18650.	138.	185.	.28
+0.	1051	15250.	128.	160.	.25
4.2	495	7194.	90*	60*	.15*

* based on linear extrapolation of pressure to zero in 50 μsec

** Qe - equivalent shock factor for 454 gm pentolite cylinder at 30.48 cm HOB

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The calculations presented in this report were not of long enough duration for direct comparison with or even extrapolation to experimental results. However, an assessment of the accuracy can be made by comparisons with previous Eulerian and Eulerian/acoustic code calculations of the same problem. Preliminary comparisons indicate that at a minimum better resolution of the shock wave was attained.

Several problems encountered during the calculation could be better handled or avoided in future attempts at obtaining a solution via Lagrangian wave propagation codes. The major recommendation would be to obtain a new code or modify an existing one incorporating a problem oriented automatic rezoning capability. Version of TOODY and STEALTH have automatic rezoning features that might be modified to handle this type of problem. However, a major effort is probably required.

If the procedure used for this calculation is repeated or continued, special caution should be used when the shock wave comes in contact with the water. Particularly away from the symmetry axis where the air shock has other then normal incidence and during the relief portion of the loading. Unreasonably large tension can be generated due to the zoning configurations on either side of the air/water interface. Investigation is required into what combinations of zone sizes will facilitate accurate transmission and reflection of the air shock wave. Zone sizes, aspect ratios and artificial viscosity coefficients have been shown to have very significant effects on Lagrangian wave

propagation calculations as discussed in reference 6.

This report verifies that a Langragian wave propagation code can be used to obtain a reasonably accurate solution to the high explosive detonation over water problem. However, the number of rezonings required (23 between 0 and 113 μsec) and the awkwardness of multiple rezonings and restartings leave a judgement on the practicality and accuracy of the procedure outlined herein open to debate.

5. Higgins, C.J., Rudeen, D.K., *Effects of Zone Size, Aspect Ratio, and Artificial Viscosity on the Accuracy of Ground Motion Calculations with Finite-Difference Codes,* AFWL-TR-77-108, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, September 1977.

SECTION V

REFERENCES

1. Lutsky, M., *Eulerian Hydrocode Calculations of the Detonation of an Explosive Cylinder Above a Water Surface: an Interim Report,* NSWC/WOL/TR-77-34, Naval Surface Weapons Center, White Oak Laboratories, Silver Spring, MD, January 1978.

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4. Thorne, B.J., and Holdridge, *The TOOREZ Lagrangian Rezoning Code,* SLA-73-1057, Sandia Laboratories, Albuquerque, New Mexico, April 1974.

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